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A novel integrated, thermally coupled fluidized bed configuration for catalytic naphtha reforming to enhance aromatic and hydrogen productions in refineries

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ABSTRACT

In the recent years, refineries have focused on developing new ways to gain more from their asset utilization owing to increasing demand for high octane gasoline. In this regard, a thermally coupled fluidized bed naphtha reactor (TCFBNR) is proposed in this study. The first and the second reactors of a conventional catalytic naphtha reactor configuration (CR) are substituted by thermally coupled fluidized bed reactors. In this novel configuration, naphtha reforming reactions which are highly endothermic are coupled with the exothermic hydrogenation of nitrobenzene to aniline. Some drawbacks of CR such as pressure drop, internal mass transfer limitation and radial gradient of concentration and temperature are successfully solved in this novel configuration. In addition to some mentioned advantages of this novel configuration, TCFBNR configuration enhances the aromatic production rate about 20.54% and 7.13% higher than CR and TCNR, respectively. Also, the TCFBNR is capable to enhance hydrogen production rate in the shell side, the aniline flow rate in the tube section and simultaneously improves the thermal behavior of endothermic side and reduces the undesirable temperature drop. The modeling results of TCFBNR is compared with the results of CR and thermally coupled fixed-bed naphtha reactor (TCNR). These studies provide a good initial insight for some modifications and revamping of the old facilities with more efficient ones.

1. Introduction

Naphtha and reformate are complex mixtures of paraffins, naphthenes and aromatics in the C_5–C_{12} range [1]. Catalytic naphtha reforming is extensively practiced in the petroleum-refining to produce high octane gasoline and hydrogen for frequently use in the hydro-treatment processes to improve the feedstock [1,2]. The process of hydrogenation, dehydrogenation and isomerization have all benefitted from the catalyst, reactor and feed treatment technologies invented for catalytic reforming processes [1]. Additionally, catalytic naphtha reforming unit is a better one to be revamped and improved owing to its considerable effect on overall refinery profits [3]. The above descriptions have motivated a variety of research on the catalytic naphtha reforming such as catalyst preparation and coking [4–9], reaction kinetics [10–15], optimization [16–21] and improvement of reaction condition [22–26].

According to the previous studies, two problems have been found in the catalytic reforming process which should be initially addressed by researchers and then by process licensors. The first problem is a carbon deposition on the catalyst surfaces which causes catalyst deactivation and catalytic bed

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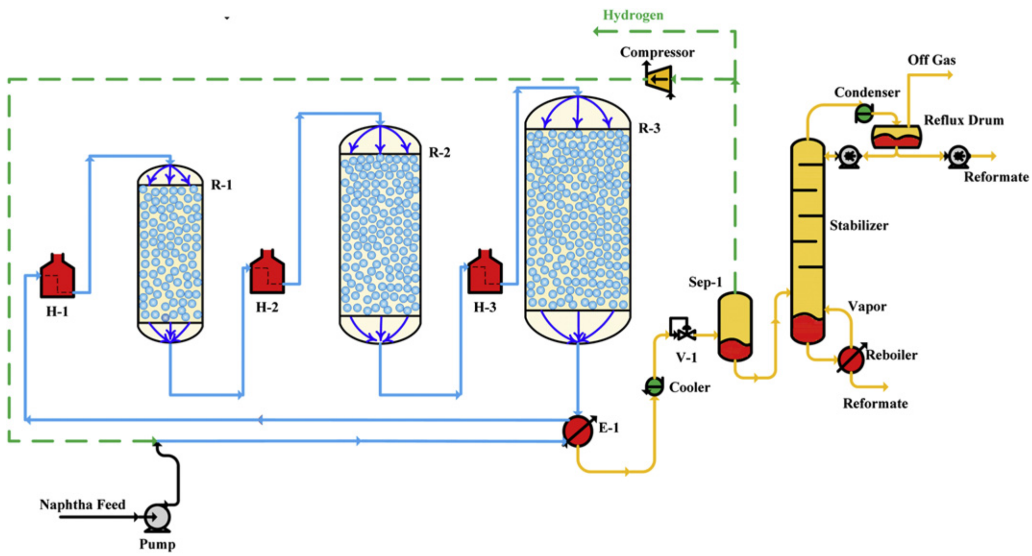

Fig. 1 – A simplified process for conventional catalytic naphtha reforming (CR).

clogging [27] while the second one is the increasing demand for high octane gasoline [1]. These problems would be addressed by simultaneous application of fluidization and process intensification concepts (using thermally coupled fluidized bed reactors).

1.1. *Fluidized bed reactor*

The application of fluidized bed reactors has gained wide interest in the chemical and petroleum industries [28]. The main advantages of fluidized bed reactors are:

- Negligible pressure drop.
- More effective use of catalyst owing to the possibility of applying smaller catalyst particles and vigorous gas–solid contact [29,30] (very small catalyst particles cannot be applied in fixed-bed reactors owing to plugging and high pressure drop).
- More compact design [31].
- The possibility of using inexpensive metal alloys for reactor vessels (due to lower operating temperature) [32].
- More effective temperature controlling and prevention from catalyst destruction owing to rapid mixing of solids in fluidized bed reactors [30].
- Continuous or periodic catalyst replacement [30,32].

A large number of theoretical and experimental studies have been recently performed on the fluidized bed reactor configurations [33–36].

1.2. *Process intensification*

Process intensification (PI) is currently one of the most significant trends in chemical engineering and process technology. It is attracting more and more attention of the research world [37]. It is the strategy of reducing environmental emissions, energy and materials consumption. Innovations in catalytic reactors, which constitute the heart of process technologies, are often the preferred starting point. In this way, multifunctional auto-thermal reactor is a novel concept in process intensification. At present, a promising field of using multifunctional auto-thermal reactors is the coupling of endothermic and exothermic reactions. In this type of reactors, an exothermic reaction is used as the heat producing source to drive the endothermic reaction(s) [38,39].

Table 1 – Specifications of conventional naphtha reactor, feed, product and catalyst of plant for fresh catalyst.

Parameter	Numerical value	Unit
Naphtha feedstock	30.41×10^3	kg/h
Reformate	24.66×10^3	kg/h
H_2/HC mole ratio	4.73	–
LHSV	1.25	h^{-1}
Mole percent of hydrogen in recycle	69.5	–
Diameter and length of 1st reactor	1.25, 6.29	m
Diameter and length of 2nd reactor	1.67, 7.13	m
Diameter and length of 3rd reactor	1.98, 7.89	m
Distillation fraction of naphtha feed and reformate		
TBP	Naphtha feed (°C)	Reformate (°C)
IBP	106	44
10%	113	73
30%	119	105
50%	125	123
70%	133	136
90%	144	153
FBP	173	181
Typical properties of catalyst		
d_p	1.2	mm
Pt	0.3	wt%
Re	0.3	wt%
S_a	220	m^2/g
ρ_B	0.3	kg/L
ε	0.36	–